Nutrients in an Eelgrass Dominated Bay: Seasonal and Diurnal Fluctuations in Dissolved Inorganic Nitrogen and Phosphorus

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Keywords: nutrients, eelgrass, nitrogen, phosphorus, water quality

INTRODUCTION

Eelgrass communities and other submerged aquatic vegetation communities may alter the concentrations of dissolved nutrients in the water column of estuaries such as Georgia Basin Puget Sound. Eelgrass plants both absorb and export dissolved nitrogen and phosphate from water through their leaves as demonstrated in laboratory and isotopic studies (McRoy and Barsdate 1970; Short and McRoy 1984). However, in bays and estuaries the role of eelgrasses in absorbing or contributing nutrients to the water column is intermixed with the rest of the eelgrass community. [“Eelgrass communities”, as used in this paper, includes the epiphytes on the leaves, the intermixed macro-algae and micro-algae, the sediments and sediment associated algae, bacteria, and fungi, and the fauna present on the vegetation, in the water, and in and on the sediments. Some of these components will be contributors to the pool of dissolved inorganic nitrogen and phosphorus, others will be removers of these nutrients. The net effect of the whole eelgrass community is the focus of the present study.] Measurements of nutrient concentrations in bays with large seagrass biomass and models of nutrient flow in seagrass communities indicate the complex interactions and differing net movements of dissolved nitrogen and phosphorus between the eelgrass community and the bulk water in these bays and estuaries (Bulthuis et al 1984; Pellikan and Nienhuis 1988; Asmus et al 1994; McMahon and Walker 1998; Dudley and Walker 2000). In the present study we consider the role of the eelgrass communities in Georgia Basin Puget Sound as part of the nearshore that interacts with dissolved inorganic nitrogen and phosphorus in the water column of the main basins. This interaction varies on daily, tidal cycle, seasonal, and interannual timescales.

In Puget Sound and Georgia Basin a variety of sources from the watershed and the ocean contribute nutrients to the pool of inorganic nitrogen and phosphorus in the water. River flow, tidal currents, and other forces move this water into and out of eelgrass communities. As water moves through eelgrass communities, the various components of the community contribute or absorb nutrients from the pool of dissolved inorganic nitrogen and phosphorus. In this study we addressed the question of the net effect of the eelgrass community on dissolved inorganic nitrogen and phosphorus in the water flowing into eelgrass areas.

Padilla Bay is a good place to address this question because of the very extensive eelgrass beds in the bay and because of the shallowness of the bay (Bulthuis 1995). The extensive eelgrass community in shallow water maximizes the opportunity for the eelgrass community to increase or decrease dissolved inorganic nutrients in the water. We addressed this question by examining nutrient data from an ongoing water quality monitoring program in Padilla Bay, Washington. We examined hourly data over a tidal cycle for tidal fluctuations and semi-monthly data over 2 years for seasonal fluctuations.

The specific questions we addressed with regard to the eelgrass community in Padilla Bay included: Does the eelgrass community measurably alter the concentrations of dissolved inorganic nitrogen or phosphorus in the water column? If so, does the eelgrass community increase or decrease the concentrations of these nutrients? Are there seasonal differences in the effect of the eelgrass community on water column nutrients? And two related questions were: What are the daily and seasonal fluctuations in dissolved inorganic nutrients in the water over the eelgrass community? and Is there evidence to indicate which nutrient may be limiting plant growth in the community?

STUDY SITE

Padilla Bay is located on the mainland in Skagit County, Washington, east of the San Juan Islands, at the southern end of the Georgia Basin, with a connecting channel in the south end of Padilla Bay to Skagit Bay in Puget Sound. Padilla Bay is an “orphaned” deltaic estuary of the Skagit River with a small remaining coastal watershed of about 9300 ha (Bulthuis 1993; 1996). Padilla Bay contains extensive intertidal flats that are covered by eelgrasses,

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Zostera marina and *Z. japonica* (Bulthuis 1995, Bulthuis and Shull 2002). Sample sites were located in mid-bay in Padilla Bay, one in the southern third of the bay (Bay View Channel site) and a second in the northern third of the bay (Ploeg Channel site, Fig. 1) Both sites are located in small to medium sized channels that drain intertidal flats that are covered with the eelgrasses (Bulthuis and Shull 2002). Flooding water moves up the channels and onto the flats from the straits and channels east of Padilla Bay. Ebbing water flows off of the intertidal flats and into larger channels that drain into these straits east of the bay. A third sample site (Gong) is located in the strait between Padilla Bay and Guemes Island in the waters that are one of the sources for flooding water that flows into Padilla Bay.

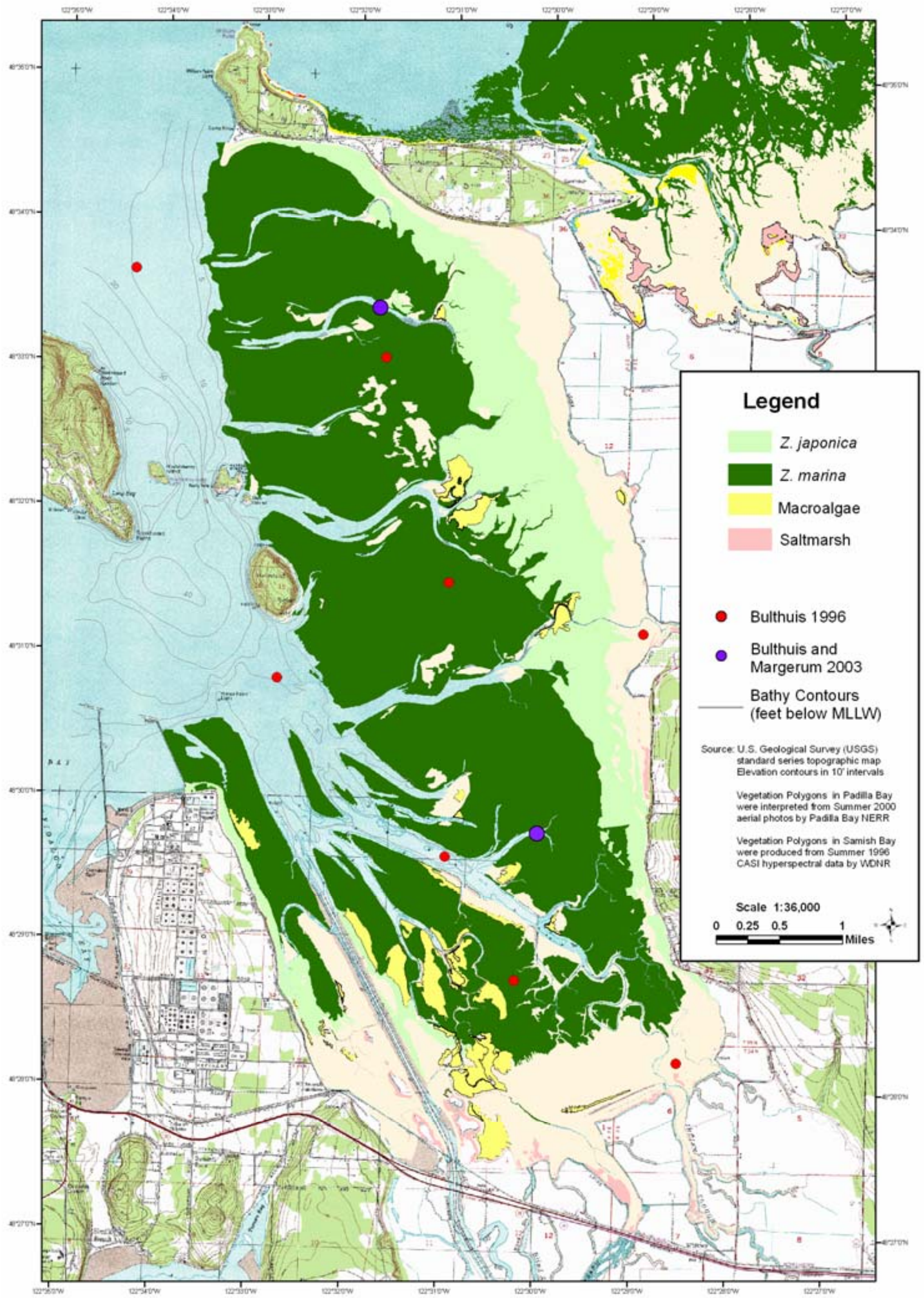

Figure 1. Samples sites (blue circles) in Padilla Bay, Washington where nutrient samples were collected semi-monthly for two years; and collected hourly during a tidal cycle each month (southern blue circle). Distribution of eelgrasses, macro-algae, and salt marshes from Bulthuis and Shull 2002.

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METHODS

Water samples were collected on two time scales. Twice a month duplicate water samples were collected at each site, kept cool until filtering the samples in the laboratory at Padilla Bay, usually within 6 hours of collection, occasionally within 24 hours of collection. Filtered samples were frozen and sent to the University of Washington Marine Chemistry Laboratory for analyses. In addition to the semi-monthly samples, once a month samples were collected every 68 minutes for 26 hours at the Bay View channel site (southern blue circle in Fig. 1). These samples were collected by an automatic sampler at about 0.5 m depth and stored in bottles in a cooled water bath until the end of the sampling cycle (26 hours) when they were returned to Padilla Bay laboratory for filtering and processing. Samples were frozen and sent to the University of Washington Marine Chemistry Laboratory for analyses. At the Marine Chemistry Laboratory nitrate, ammonium, nitrite, and soluble reactive phosphate were determined by automated methods (Armstrong et al 1967; Slawyk and MacIsaac 1972; Bernhadt and Wilhelms 1967).

RESULTS AND DISCUSSION

Nitrate was the dominant form of dissolved inorganic nitrogen in Padilla Bay in most water samples (Fig. 2). Nitrite concentrations were always low and only a minor constituent of dissolved inorganic nitrogen (Fig. 2). Ammonium concentrations were almost always greater than nitrite but were low and variable compared to nitrate (Fig. 2). Occasionally during summer, when the concentrations of nitrate were very low, ammonium was the predominant form of dissolved inorganic nitrogen in the water (Fig. 2). Because nitrite and ammonium concentrations were low and variable and eelgrasses and many plants and bacteria can absorb all three forms of dissolved nitrogen either directly or indirectly, dissolved inorganic nitrogen (DIN: nitrate plus nitrite plus ammonium) is used throughout the present study.

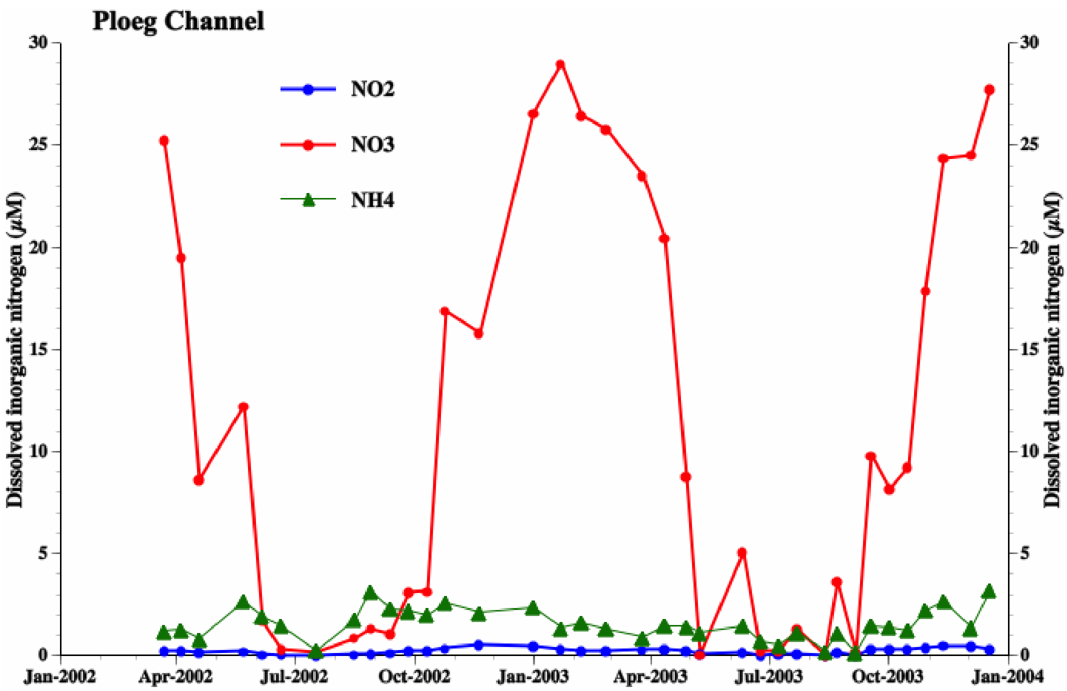

Figure 2. Nitrate, nitrite, and ammonium in water collected 0.5 m above the bottom in Ploeg Channel (northern blue circle in Fig. 1) during 2002 and 2003. Mean of duplicate samples collected semi-monthly.

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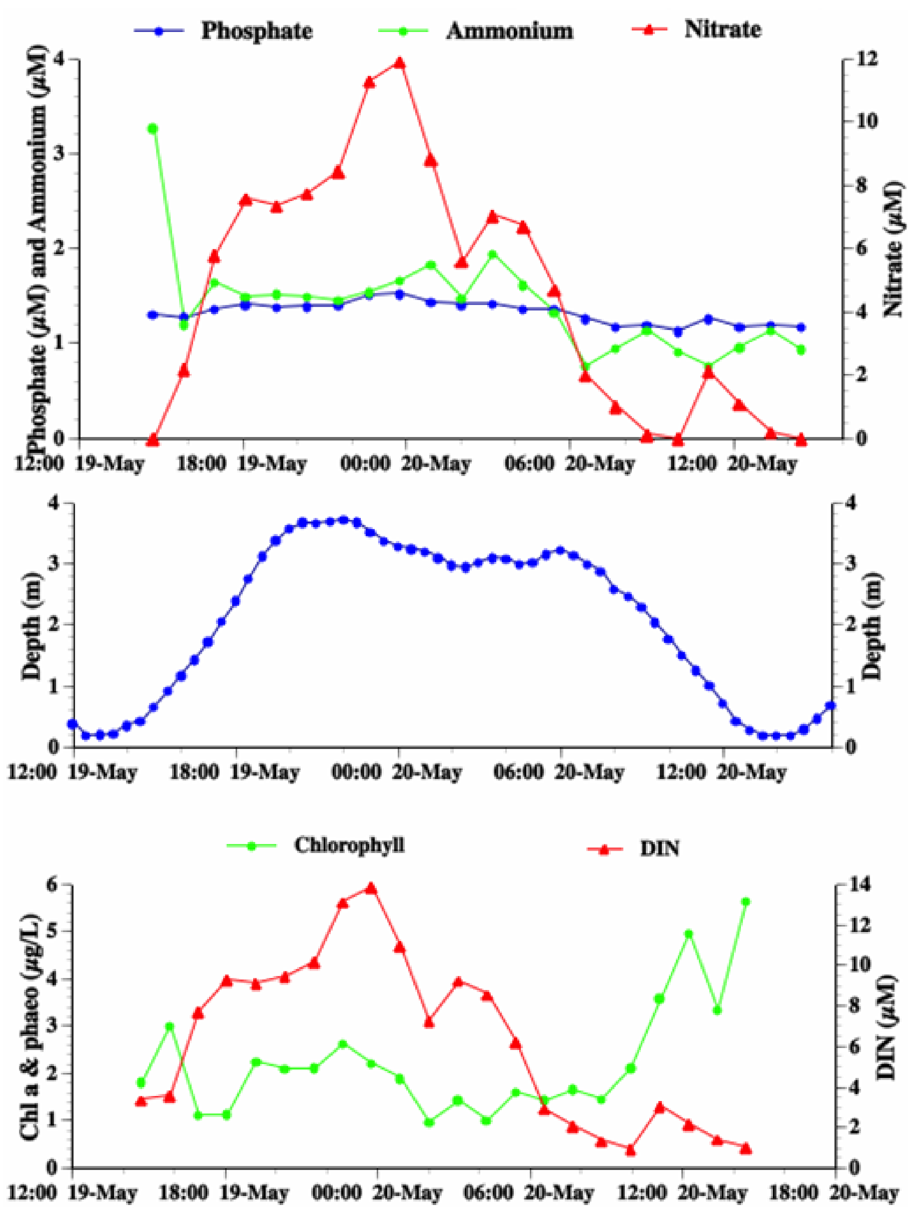
During a 26 hour sampling series on May 19-20, 2003, the higher low tide and lower high tide in Padilla Bay were very similar in height (Fig.3). On these days, water flowed into Padilla Bay from the straits and channels east of the bay, flooded over the eelgrass flats and remained in the bay for about twelve hours. As water flooded into the bay past the Bay View Channel site, the concentration of DIN increased from about 3 µM to 9 and then 14 µM (Fig. 3). These data indicate that DIN concentrations in the straits and channels east of Padilla Bay were higher then the residual water in the bay at low tide. As the water remained in the bay over the next twelve hours, the concentration of DIN decreased (Fig. 3). It is suggested that this decrease is due to the biological activity of the eelgrass community. The low concentrations of chlorophyll in this water indicate that phytoplankton were not the community responsible for the decreasing DIN. In contrast, the concentrations of soluble reactive phosphate remained similar throughout the tidal cycle (Fig. 3). It is suggested that, although there may have been exchange between the eelgrass community and the soluble reactive phosphate (SRP) in the water, the eelgrass community did not have a measurable net effect on the concentration of SRP.



Figurre 3. Nitrate, ammonium, dissolved inorganic nitrogen (DIN), phosphate, and chlorophyll *a* concentrations, and water depth, at 0.5 m from the surface in Bay View Channel in samples collected every 68 minutes for 26 hours May 19-20, 2003.

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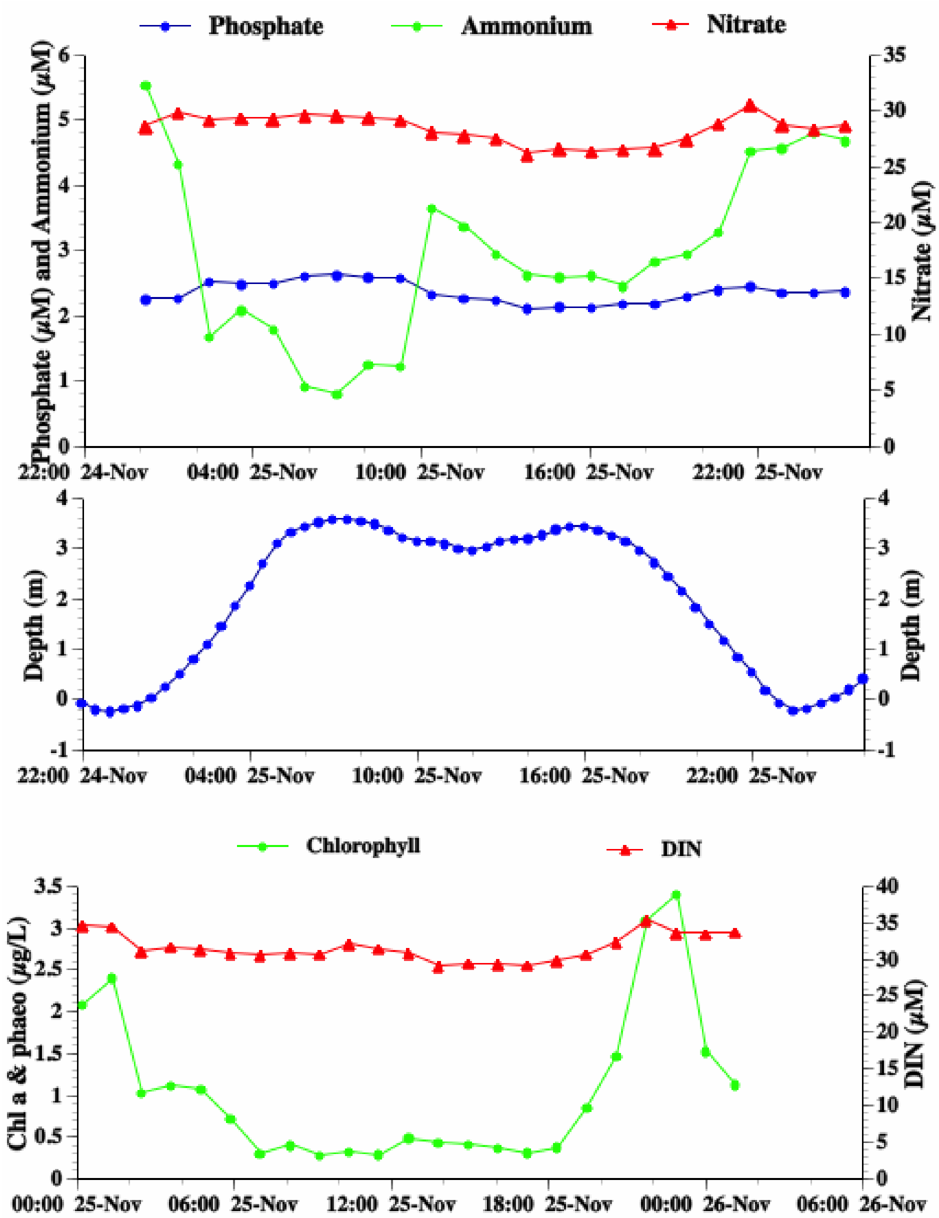
In contrast to the pattern seen in May, both DIN and soluble reactive phosphate during a 26 hour sampling series in November did not change during the tidal cycle (Fig. 4). DIN concentrations in November were more than twice the highest concentrations that were measured in May (cf. Figs 3 and 4). Soluble reactive phosphate concentrations were similar throughout the tidal cycle in November and were about one and a half times the concentrations measured in May (cf. Figs 3 and 4). It is suggested that the lack of change in the concentrations of both DIN and SRP indicate that the eelgrass community was not having a net effect on the concentration of dissolved inorganic nutrients in the water because of low rates of biological activity during November.



Figurre 4. Nitrate, ammonium, dissolved inorganic nitrogen (DIN), phosphate, and chlorophyll *a* concentrations, and water depth, at 0.5 m from the surface in Bay View Channel in samples collected every 68 minutes for 26 hours November 25-26, 2003.

The seasonal pattern of DIN at the Ploeg Channel sample site in Padilla Bay was one of high concentrations during late autumn and winter and much lower concentrations during summer (Fig. 5). Concentrations of DIN were generally below 5 µM during June to August and generally above 25 µM during December through February (Fig. 5). The concentrations of SRP were also somewhat higher in winter than in summer, but the seasonal fluctuations were much less pronounced than for DIN (Fig. 5).

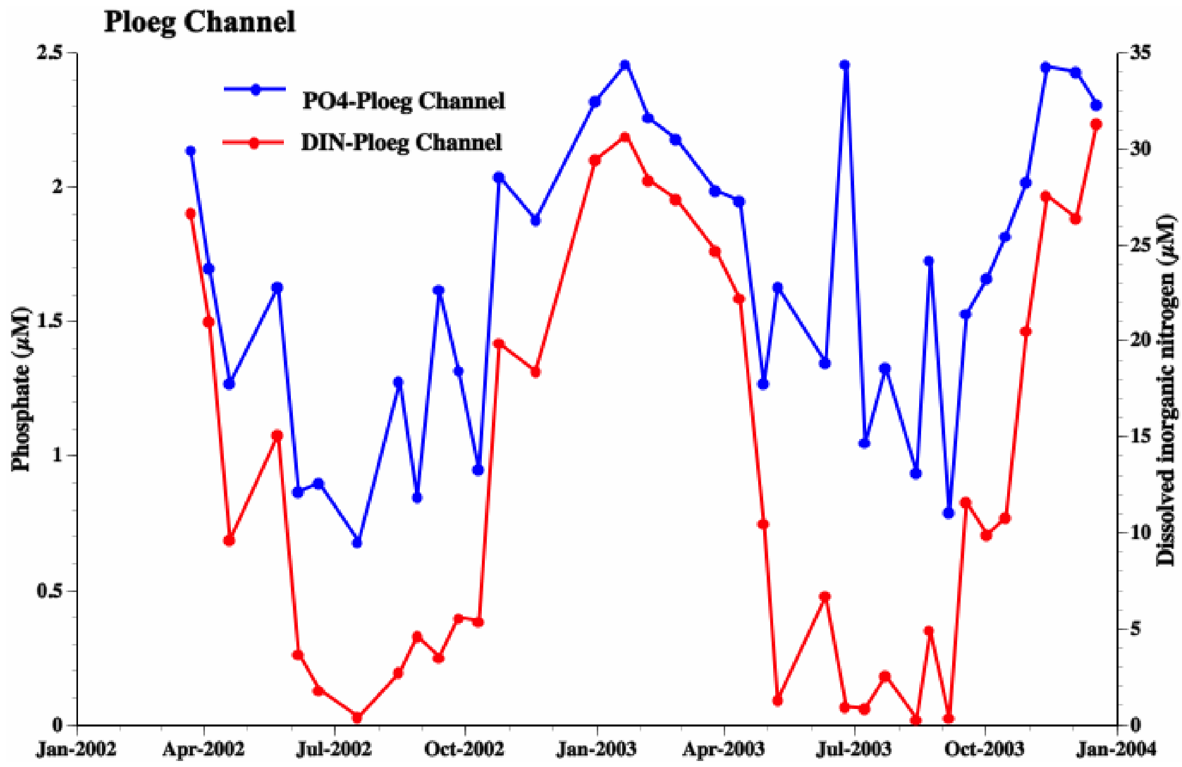


Figure 5. Dissolved inorganic nitrogen (DIN) and soluble reactive phosphate (PO4) in water collected 0.5 m above the bottom in Ploeg Channel during 2002 and 2003. Mean of duplicate samples collected semi-monthly.

The ratio of dissolved inorganic nitrogen to phosphorus fluctuated seasonally at the Bay View and Ploeg Channel sites in the middle of Padilla Bay (Fig. 6). The ratio of 16:1 N:P has been used as an indication of nitrogen vs. phosphorus limitation when these nutrients are growth limiting to plants (Ryther and Dunstan 1971). In central Padilla Bay, the N:P ratio was always below 16:1 during 2002 and 2003 and decreased to ratios below 5 during summer (Fig. 6). These ratios indicate that plant growth that was limited by nutrient concentrations in the water was likely to be nitrogen limited. This is consistent with studies of the phytoplankton in Padilla Bay which Bernhard and Peele concluded were nitrogen limited during part of the summer; and for eelgrasses in Padilla Bay which Williams and Ruckelshaus concluded were nitrogen limited based on studies conducted in April and August (Williams and Ruckelshaus 1993, Bernhard and Peele 1997).

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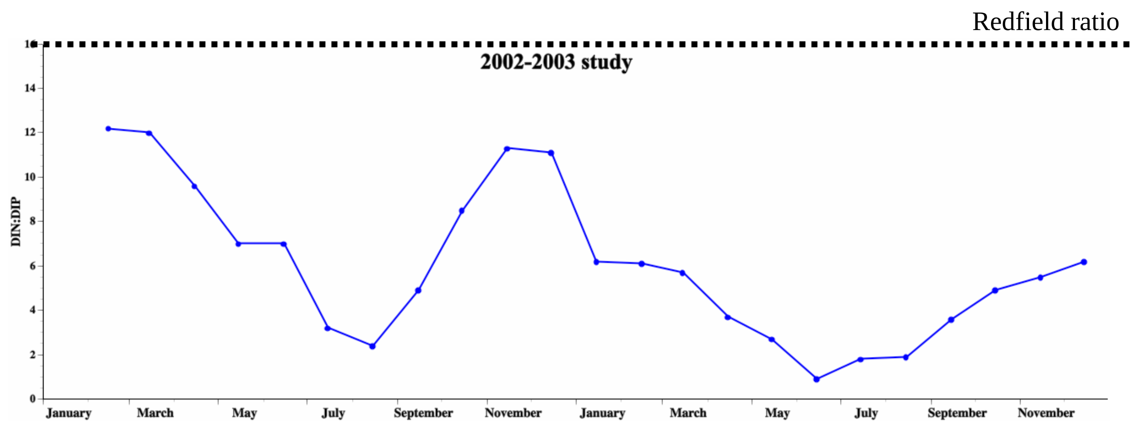

Figure 6. The ratio of dissolved inorganic nitrogen to soluble reactive phosphate in Padilla Bay, Washington during 2002 to 2003. Monthly means of duplicate samples taken twice a month at two sites in mid-bay.

The results presented in this report indicate that the eelgrass community in Padilla Bay absorbs dissolved inorganic nitrogen from the water as Georgia Basin Puget Sound water flows over the eelgrasses in summer. Similar processes are probably occurring in eelgrass beds throughout Georgia Basin and Puget Sound, although less extensive beds of eelgrass may make it difficult to measure changes in concentration during a single tidal cycle. However, these data suggest that eelgrass communities in Puget Sound and Georgia Basin may play an important role in reducing DIN in the water column during the growing season, particularly in shallow and nearshore areas. Thus, eelgrasses may help reduce some of the negative impacts of increased nutrient loading and eutrophication. However, eelgrasseses are also vulnerable to increased nutrient loading since there are numerous estuaries where nutrient loading has overwhelmed the seagrass community and increased nutrients have resulted in increased phytoplankton, epiphytes, and/or macro-algae and caused death and loss of extensive areas of seagrasses (Kemp et al 1983; Orth and Moore 1983; Cambridge et al 1986; Valiela et al 1997).

CONCLUSIONS

This study addressed several questions regarding the effect of eelgrass communities on dissolved inorganic nitrogen and soluble reactive phosphate in the waters of Puget Sound and Georgia Basin. In Padilla Bay, the eelgrass community measurably decreased the concentrations of dissolved inorganic nitrogen during the summer but not so for soluble reactive phosphate. During winter, the eelgrass community did not alter the concentrations of dissolved inorganic nitrogen or soluble reactive phosphate. The concentrations of nutrients over the eelgrass community fluctuated seasonally, with dissolved inorganic nitrogen concentrations about five times higher in winter than in summer and soluble reactive phosphate concentrations about one and half times higher in winter. Nitrogen appears to be the limiting nutrient for plants in the eelgrass community in summer. These data indicate the eelgrass communities throughout Georgia Basin and Puget Sound may act to decrease water column nutrient concentrations over the eelgrass beds during summer.

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